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The Impact of Ballet on Hip Joint Muscle Strength: A Study Based on Isokinetic Technology

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Abstract: *This study utilized isokinetic strength testing technology to assess hip flexion-extension and internal-external rotation muscle strength in 24 ballet students and 24 regular university students, in order to explore the impact of ballet training on hip joint muscle strength. The results showed that the flexion-extension muscle group in the ballet group had significantly higher values in five metrics (peak torque, relative peak torque, relative work, relative peak power, and peak torque ratio) compared to the control group (P<0.05). The male ballet participants' flexion-extension peak torque (180°/s: 265.26±39.55 N·m) was comparable to that of fencing athletes. In the internal-external rotation tests, the ballet group exhibited significantly higher external rotation muscle metrics, with an increase of 32.5-74.4%, while the internal rotation metrics showed no significant differences when compared to the control group. Interestingly, the female ballet group showed a 19.4% reduction in internal rotation work at 180°/s (P<0.05). The study suggests that long-term ballet training significantly enhances hip flexion-extension strength and external rotation strength, forming a specialized characteristic of external rotation dominance and flexion-extension synergy. However, the development of the internal rotation muscle group lags behind.*

Keywords: *ballet; hip joint; isokinetic; muscle strength*

1. Introduction

The hip joint, as the core pivot of the human kinetic chain, plays a dual role in dance movements, serving both as a biomechanical conduit and providing dynamic stability. Anatomically, this joint possesses three-axis motion capabilities, including flexion-extension in the sagittal plane, adduction-abduction in the coronal plane, and internal-external rotation in the horizontal plane. The achievement of these movements relies on the synergistic action of 22 muscles around the hip joint. Based on their spatial distribution and functional characteristics, these muscles can be categorized into four main muscle groups: the flexors at the front (mainly including the iliopsoas and rectus femoris), the extensors at the back (primarily the gluteus maximus and the long head of the biceps femoris), the abductors on the lateral side (with the gluteus medius and minimus at the core), and the adductors on the medial side (led by the adductor magnus and long adductor).

The strength of the hip joint muscle group is fundamental to ensuring the quality of dance movements. These muscles are crucial not only for joint stability but also for supporting the body's weight and generating the necessary force for movement. The hip joint connects the femur and pelvis and can bear significant forces during standing and movement. While its structure poses certain challenges to stability, it allows for a wide range of motion. In dance, the thigh can flex and extend around the hip joint's frontal axis, such as in front and back leg movements; it can externally and internally rotate around the vertical axis, as seen in outward and inward leg movements; it can also abduct and adduct around the sagittal axis, such as in side leg movements in dance; and it can perform circular movements around the hip joint, such as leg rotation movements. The range of motion of the hip joint is one of the key physical attributes for measuring an excellent dancer, and dancers must possess exceptional control to maintain both strength and flexibility in the hip joint. This enables them to improve the quality of lower limb movements by better utilizing the hip joint in executing dance movements. Maintaining the body's center of gravity balance and stability during dance movements depends on the strength and agility of the hip joint muscles. Some movements that require speed in the thigh and feet demand that the dancer maintains pelvic stability to achieve them. When performing front or back leg poses such as a developpé or arabesque in ballet, the dancer must achieve a high degree of leg extension, for which good strength and flexibility in the hip joint muscles are indispensable.

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To study the isokinetic strength characteristics of the hip joint in ballet students, this research employs isokinetic technology to test the hip joint flexion-extension and internal-external rotation torque of ballet students. Simultaneously, the same testing methods are applied to a control group of regular university students for comparison. By comparing the test results between the two groups and contrasting them with other existing research findings, this study provides an in-depth analysis of the isokinetic strength characteristics of the hip joint in ballet students, offering valuable scientific evidence for dance training.

2. Background

Isokinetic muscle strength testing, as a standardized technique for quantifying muscle function, has established a mature paradigm in the field of sports science for analyzing the biomechanical characteristics of the hip joint. However, there remains a significant research gap regarding the analysis of muscle strength characteristics in the context of dance. In sports science, studies utilizing isokinetic technology have revealed sport-specific patterns in how different athletic disciplines impact hip joint strength, offering important references for dance-related research.

Existing studies have shown that badminton players exhibit higher peak torque and relative peak torque in the flexor and extensor muscles of the non-dominant hip at angular velocities of 60°/s and 180°/s, whereas the opposite trend is observed at 300°/s. This indicates that muscle strength performance is dynamically influenced by movement speed. Moreover, the bilateral development of muscle strength in badminton reflects the sport's technical emphasis on symmetrical force production. [1]

Comparative studies on cyclists have shown that professional athletes demonstrate significantly greater peak torque in the dominant and non-dominant hip extensors at 60°/s compared to non-professionals. At 240°/s, all variables except dominant-side extensors also showed significant differences, confirming that systematic training plays a key role in improving sport-specific muscle strength. [2]

Research on shot putters has found that although isokinetic performance of the hip flexor and extensor muscles was strong, there were issues in practical performance such as poor timing and low efficiency in force transfer during throws. This suggests the need to simultaneously optimize technical execution and basic strength development. [3]

Studies on weightlifters pointed out that hip extensor explosive strength increases with movement speed, which contrasts with the strength development pattern observed in the knee joint. This unique pattern sometimes leads to flexor-extensor strength ratios that exceed normal ranges, increasing the risk of injury. [4]

Research related to Tai Chi found that, across speeds ranging from 60°/s to 240°/s, practitioners consistently showed stronger hip extensors compared to flexors. This was particularly evident among older adults, who demonstrated significant advantages in peak torque, average work, and power. These findings affirm the benefits of Tai Chi in enhancing hip joint strength, while also highlighting the need to strengthen underdeveloped flexor muscles. [5] [6]

In canoeing athletes, comparative data indicated significant asymmetry between the hip flexor/extensor peak torque of the kneeling leg and the supporting leg. For example, at 60°/s, the peak torque of the flexor on the kneeling side reached 105.5 N·m, compared to only 95.5 N·m on the supporting side. This asymmetrical development directly reflects how sport-specific movement patterns drive adaptive structural changes in the body. [7]

In summary, the characteristics of different sports and their corresponding training methods jointly shape the unique strength profiles of the hip joint. Speed sensitivity is especially prominent in rapid, direction-changing sports such as badminton; strength symmetry is well-maintained in cyclic sports such as cycling; while traditional disciplines like Tai Chi exhibit speed-dependent strength development patterns. Notably, the coordination between basic strength levels and technical application, the balance of unilateral versus bilateral strength development, and the appropriate ratio between flexor and extensor muscles are all key factors that impact both performance and injury prevention. These insights provide a multidimensional analytical framework for future research into hip joint function in dance.

3. Research Subjects

A total of 48 university students were selected as participants for this study, including 12 male and 12 female ballet students from the 2013 and 2014 cohorts of the Beijing Dance Academy, and 12 male

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and 12 female students from the 2014 cohort of the School of Information Engineering at Minzu University of China (For specific details, see Table 1). The ballet students served as the experimental group, while the non-dance university students (with no ballet training experience) formed the control group. All participants were in good health, with no significant injuries in the recent past, and no discomfort was reported during testing.

Table 1 Demographic Characteristics of Research Subjects

Subject	Gender	Number	Age (years)	Height (cm)	Weight (kg)	Training Duration (years)
Ballet	Female	12	20.9±1.8	166.6±6.1	51.2±4.5	10±1.7
	Male	12	22.2±2.6	181.4±4.0	71.6±7.4	10±2.0
Non-dance	Female	12	0.6±0.8	162.3±6.1	52.2±6.3	0
	Male	12	20.7±0.9	170.9±4.4	61.7±6.3	0

4. Methodology

The isokinetic muscle strength testing in this study was conducted using the German-made Isomed 2000 isokinetic testing system to measure various isokinetic parameters.

The test angular velocities were set at 60°/s and 180°/s, and the test mode was concentric-concentric. Each completed cycle of joint extension or flexion was counted as one repetition. At each angular velocity, participants performed four cycles, which constituted one set. For each type of movement, two sets were conducted—one at 60°/s and the other at 180°/s—with a 15-second rest between sets. During repeated testing, the range of motion for the joints was kept consistent.

The procedure began with slow-speed testing (angular velocity of 60°/s), performing four cycles per set, ensuring continuous force production and achieving the set range of motion for each cycle. Afterward, the same movements were tested at a faster speed (angular velocity of 180°/s). After completing one side, testing was repeated on the other side. The joint motion types tested included: flexion-extension and internal-external rotation.

The hip joint testing parameters included: peak torque (PT), relative peak torque (PT/BW), relative work (TW/BW), relative peak power (PP/BW), and peak torque ratio (H/Q), totaling five metrics.

Isokinetic muscle strength test data were analyzed using SPSS software for statistical analysis. The data were input into a computer and stored in Excel format. SPSS 11.0 statistical software was used to process the data. Results are presented as means and standard deviations (±S), and an independent samples t-test was used to assess intergroup differences. A significance level of $P<0.05$ was considered statistically significant, while $P<0.01$ was considered highly significant.

5. Results and Analysis

This study used SPSS software for statistical analysis of the collected data and found no significant differences in the left and right hip joint test results between ballet students and regular university students. Therefore, this study only discusses the data for the right side.

5.1 Hip Joint Flexion-Extension

5.1.1 Peak Torque (PT)

Table 2: Peak Torque of Hip Joint Flexion-Extension (Units: N·m)

		Flexion		Extension	
Angle Velocity (°/s)		60	180	60	180
Male	Non-dance	108.91±22.35	79.58±21.04	223.02±58.21	178.05±50.23
	Ballet	148.28±19.78***	118.88±23.37***	322.76±40.48***	265.26±39.55***
Female	Non-dance	59.99±10.57	51.58±19.70	139.27±45.59	101.30±43.37
	Ballet	83.37±18.41*	73.93±24.31	167.58±26.3	129.9±34.41

Note: *Significant difference (P 0.01≤P<0.05); **Highly significant difference (P<0.01); ***Extremely significant difference (P<0.001).

The test results (Table 2) indicate that ballet students performed significantly better than the non-dance group in terms of hip flexion-extension peak torque at all angular velocities, with male ballet students showing the most remarkable differences. At a 60°/s angular velocity, male ballet students achieved a peak torque of 148.28±19.78 N·m in flexion, representing a 36.2% increase over the non-dance group, and the difference was extremely significant (P<0.001). This advantage increased to 49.4% at the faster speed of 180°/s. For the extension muscles, male ballet students generated a peak torque of 322.76±40.48 N·m at 60°/s, a 44.7% increase over the non-dance group, demonstrating remarkable explosive power output.

Among the female participants, the flexion peak torque at 60°/s (83.37±18.41 N·m) showed a significant difference (P<0.05), but other metrics still showed clear numerical advantages. For example, the flexion torque at 180°/s was 43.3% higher than the non-dance group, and the extension torque at 60°/s and 180°/s was 20.3% and 28.3% higher, respectively.

This phenomenon indicates that long-term ballet training significantly improves the maximal strength of the hip joint flexion-extension muscles in the lower limbs. This is likely related to the fact that ballet students, especially male dancers, must perform numerous technical movements like jumps and turns, which require strong lower limb strength. The main muscles responsible for hip flexion include the iliopsoas and rectus femoris, while hip extension is driven by the gluteus maximus and hamstrings. Hip flexion-extension strength is the foundation for executing a variety of lower limb movements. As the largest joint in the lower limb, the hip joint strength directly affects the quality and quantity of most lower limb movements in dancers. Ballet training extensively targets these muscles, whether through exercises like Plie, Grand Battement Jete, or Adagio, all of which train the hip flexion-extension muscles. High-strength demands are also placed on the hip joint muscles during technical skills, such as the grand jeté (leap), where rapid, high-force movements in the air require substantial hip flexion-extension strength.

A further analysis revealed that the hip joint flexion-extension peak torque of the right side in male ballet students was similar to that of elite male fencing athletes [8]. This may be due to the similar demands placed on male dancers and fencers for lower limb hip joint strength. However, due to the specificity of fencing training, the strength requirements for the left and right legs differ, and this study only compared the right leg for reference.

5.1.2 Relative Peak Torque (BW)

Table 3: Relative Peak Torque of Hip Joint Flexion-Extension (Units: Nm/Kg)

		Flexion		Extension	
Angle Velocity (°/s)		60	180	60	180
Male	Non-dance	1.19±0.15	0.95±0.15	2.5±0.32	1.86±0.26
	Ballet	2.07±0.17*	1.65±0.21**	4.54±0.69*	3.71±0.49**
Female	Non-dance	1.15±0.18	0.97±0.25	2.65±0.68	1.91±0.69
	Ballet	1.62±0.28***	1.43±0.39	3.28±0.48*	2.54±0.55*

Note: *Significant difference (P 0.01≤P<0.05); **Highly significant difference (P<0.01); ***Extremely significant difference (P<0.001).

The relative peak torque data further reveals the effect of ballet training on strength development (as shown in Table 3). Male ballet participants achieved a relative peak torque of 2.07±0.17 Nm/kg for flexion at 60°/s, an increase of 74.0% compared to the non-dance group (P<0.05), and this advantage increased to 73.7% at 180°/s (P<0.01). The extension muscles showed even more remarkable performance. Male ballet participants generated a relative peak torque of 4.54±0.69 Nm/kg at 60°/s, a 81.6% increase over the non-dance group, and this strength advantage remained significant even after controlling for body weight.

For females, the ballet group showed a 40.9% increase in relative flexion torque at 60°/s (1.62±0.28 Nm/kg, P<0.001) compared to the non-dance group. Extension torque at 60°/s and 180°/s also showed 23.8% and 33.0% increases, respectively, both of which were statistically significant (P<0.05).

These results suggest that long-term ballet training significantly enhances the relative maximum strength of the hip joint flexion-extension muscles in the lower limbs. Moreover, comparative analysis revealed more pronounced differences in relative peak torque and peak torque ratios of these muscles between female ballet majors and non-dancing college students (P<0.05). This is likely related to the strict weight control requirements for female ballet dancers, as their body weight is typically lower than that of regular university students. Weight is one of the most significant factors influencing absolute strength. Relative peak torque, which considers the ratio of peak torque to body weight, provides a more objective and effective measure of the differences in relative strength between ballet students and regular university students.

ISSN 2618-1576 Vol. 7, Issue 2: 46-55, DOI: 10.25236/FSR.2025.070208

5.1.3 Relative Work (TW/BW)

Table 4: Relative Work of Hip Joint Flexion-Extension (Units: J/Kg)

		Flexion		Extension	
Angle Velocity (°/s)		60	180	60	180
Male	Non-dance	1.84±0.37	1.21±0.35	3.75±1.0	2.93±0.89
	Ballet	2.16±0.31*	1.55±0.23**	4.88±0.87**	4.15±0.81**
Female	Non-dance	1.25±0.16	0.79±0.16	2.87±0.78	1.83±0.87
	Ballet	1.85±0.35***	1.23±0.36*	3.80±0.62	2.59±0.83*

Note: *Significant difference (P 0.01≤P<0.05); **Highly significant difference (P<0.01); ***Extremely significant difference (P<0.001).

The test data (Table 4) shows that ballet students generally performed better than the non-dance group in terms of relative work for the hip flexion-extension muscles. In the male group, the relative work for flexion at 60°/s was 2.16±0.31 J/kg, a 17.4% increase compared to the non-dance group (P<0.05), and the increase was 28.1% at 180°/s (P<0.01). The performance in extension was even more pronounced, with the ballet male group showing relative work of 4.88±0.87 J/kg at 60°/s and 4.15±0.81 J/kg at 180°/s, both significantly higher than the non-dance group (30.1% and 41.6% increases, respectively, both P<0.01).

In the female group, the relative work for flexion at 60°/s was 1.85±0.35 J/kg, which was 48.0% higher than the non-dance group (P<0.001), and at 180°/s, the increase was 55.7% (P<0.05). For extension, a 41.5% increase was observed at 180°/s (P<0.05), but no significant change was seen at 60°/s.

This difference is closely related to the continuous strength output requirements in ballet training. Long-term ballet training effectively enhances the ability of the hip flexion-extension muscles to sustain force, leading to a significant increase in relative work. Ballet training involves many controlled movements, such as Attitude and Arabesque. To maintain the aesthetic beauty of these poses and achieve higher amplitudes for longer durations, the hip flexion-extension muscles are continuously engaged, thereby training the muscles' ability to sustain force.

5.1.4 Relative Peak Power (PP/BW)

Table 5: Relative Peak Power of Hip Joint Flexion-Extension (Units: W/Kg)

		Flexion		Extension	
Angle Velocity (°/s)		60	180	60	180
Male	Non-dance	1.119±0.22	1.95±0.57	2.26±0.69	4.37±1.53
	Ballet	1.52±0.13***	2.76±0.36***	3.29±0.58***	6.77±1.36***
Female	Non-dance	0.78±0.12	1.23±0.23	1.78±0.52	2.79±1.34
	Ballet	1.14±0.21***	1.8±0.48**	2.27±0.39*	3.82±1.25*

Note: *Significant difference (P 0.01≤P<0.05); **Highly significant difference (P<0.01); ***Extremely significant difference (P<0.001).

The relative peak power test results (Table 5) further reveal the effect of ballet training on the development of explosive strength. In the male group, the relative peak power for flexion at 60°/s was 1.52±0.13 W/kg, a 35.7% increase compared to the non-dance group (P<0.001), and the increase was 41.5% in the 180°/s high-speed test (P<0.001). The extension performance was even more prominent, with the ballet male group generating 6.77±1.36 W/kg of power at 180°/s, a 54.9% increase compared to the non-dance group (P<0.001).

In the female group, the ballet students showed 46.2% and 46.3% improvements in relative peak power for flexion at 60°/s and 180°/s, respectively (P<0.001 and P<0.01), while the extension power at 60°/s and 180°/s increased by 27.5% (P<0.05) and 36.9% (P<0.05), respectively.

The advantage in power output can be attributed to the neuromuscular coordination patterns developed through ballet training. The test results show that long-term professional ballet training significantly improves the relative peak power of the hip flexion-extension muscles in the lower limbs. After extensive training, ballet students have developed proper muscle activation habits and movement patterns, allowing them to generate force more rapidly and efficiently in a given time, reaching maximum power output. Additionally, their body weight is lower than that of non-dance students, which contributes to the higher relative peak power of the lower limb hip flexion-extension muscles in ballet students.

ISSN 2618-1576 Vol. 7, Issue 2: 46-55, DOI: 10.25236/FSR.2025.070208

5.1.5 Peak Torque Ratio (H/Q)

Table 6: Peak Torque Ratio of Hip Joint Flexion-Extension

		Flexion		Extension	
Angle Velocity (°/s)		60	180	60	180
Male	Non-dance	0.51±0.13	0.47±0.13	2.07±0.47	2.31±0.69
	Ballet	0.47±0.09	0.46±0.1	2.22±0.43	2.3±0.53
Female	Non-dance	0.46±0.13	0.63±0.48	2.31±0.58	2.04±0.76
	Ballet	0.5±0.06	0.57±0.12	2.05±0.29	1.84±0.44

Note: After Bonferroni correction, no statistical differences were found between groups ($P > 0.05$).

From Table 6, it can be seen that the peak torque ratio for hip flexion-extension at 60°/s and 180°/s in ballet students is similar to that of non-dance students, with no significant differences ($P > 0.05$).

This result indicates that long-term ballet training does not affect the hip flexion-extension peak torque ratio in the lower limbs. Ballet students have a similar ratio of maximum flexion to extension strength in the hip joint compared to the general population. The strength training and requirements for the hip flexors and extensors in ballet are relatively balanced and correspond to the proportion needed in daily life. The increase in hip joint strength due to professional training occurs uniformly on both sides of the hip flexor-extensor muscles, rather than focusing on one side, hence there is no professional specificity.

5.2 Hip Joint Internal- External Rotation

5.2.1 Peak Torque (PT)

Table 7: Rotation Peak Torque of Hip Joint Internal and External (Unit: N·m)

		Internal Rotation		External Rotation	
Angle Velocity (°/s)		60	180	60	180
Male	Ballet	27.2±5.62	22.8±4.39	37.64±6.45	31.7±6.1
	Non-dance	22.03±3.23*	18.77±3.05*	24.18±3.16***	20.64±2.49***
Female	Ballet	14.54±3.16	12.16±2.27	22.11±2.41	17.95±2.73
	Non-dance	14.39±2.96	12.48±2.12	15.61±2.86***	13.2±2.04***

Note: *Significant differences when comparing ballet students and non-dance students: *P $0.01 \le P < 0.05$; **$P<0.01$; ***$P<0.001$.

The test data (Table 7) shows that ballet students have a significant advantage in the maximum strength output of the hip external rotators. In the male ballet group, the peak torque of external rotation at 60°/s reached 37.64±6.45 N·m, an increase of 55.8% compared to the non-dance group ($P < 0.001$), and this advantage further expanded to 53.6% in the 180°/s high-speed test ($P < 0.001$). For internal rotation, the male ballet group achieved 27.2±5.62 N·m at 60°/s and 22.8±4.39 N·m at 180°/s, an increase of 23.5% ($P < 0.05$) and 21.5% ($P < 0.05$) compared to the non-dance group.

In the female group, the ballet group's external rotation at 60°/s (22.11±2.41 N·m) was 41.6% higher than the non-dance group ($P < 0.001$), and the increase was 36.0% at 180°/s ($P < 0.001$). However, in terms of internal rotation, there was no significant difference at 60°/s, with the ballet group (14.54±3.16 N·m) similar to the non-dance group (14.39±2.96 N·m) ($P = 0.892$), and at 180°/s, the ballet group's torque was even slightly lower by 1.2 N·m ($P = 0.314$).

These results show that long-term ballet training has a significant impact on increasing the maximum strength of hip external rotation in the lower limbs, while there is not much difference in the maximum internal rotation strength between ballet students and the general population. In fact, female ballet students even show slightly lower internal rotation strength compared to the general population at higher speeds. However, their external rotation strength is significantly higher. This is closely related to the nature of ballet training, which emphasizes external rotation of the hip joint as a key aesthetic feature of the art form. The primary muscles involved in hip external rotation include the gluteus maximus, gluteus medius, piriformis, and iliopsoas. In ballet, from basic positions like the first position (première position), these muscles are constantly trained, especially in poses like Passé, which require significant muscle strength. As a result, ballet students show significant improvement in hip external rotation strength.

Due to the specialized nature of ballet training, there are very few exercises and movements that involve internal rotation of the hip, which explains why the internal rotation strength of ballet students is

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similar to, or even lower than, that of the general population. This could also be due to the excessively developed and tight external rotator muscles, which may inhibit internal rotation. In comparison to other dance forms, such as Chinese classical dance, which incorporates internal rotation movements, ballet students likely exhibit stronger external rotation strength, not only in comparison to the general population but also to students in other dance disciplines.

5.2.2 Relative Peak Torque (BW)

Table 8: Relative Peak Torque of Hip Joint Internal and External Rotation (Unit: Nm/Kg)

		Internal Rotation		External Rotation	
Angle Velocity (°/s)		60	180	60	180
Male	Ballet	0.38±0.08	0.32±0.06	0.53±0.1	0.44±0.08
	Non-dance	0.36±0.05	0.32±0.04	0.40±0.05***	0.34±0.04***
Female	Ballet	0.28±0.05	0.24±0.04	0.44±0.07	0.36±0.07
	Non-dance	0.28±0.06	0.24±0.05	0.3±0.06***	0.25±0.04***

Note: *Significant differences when comparing ballet students and non-dance students: *P 0.01≤P<0.05; **P<0.01; ***P<0.001.

The test data (Table 8) shows that ballet students exhibit a systematic advantage in relative peak torque for hip external rotation. In the male ballet group, the relative peak torque of external rotation at 60°/s reached 0.53±0.10 Nm/kg, which was 32.5% higher than the non-dance group ($P < 0.001$), and the increase at 180°/s was 29.4% ($P < 0.001$). In the female group, relative torque at 60°/s and 180°/s increased by 46.7% and 44.0%, respectively, both achieving highly significant differences ($P < 0.001$).

In terms of internal rotation, no significant differences were observed between the ballet and non-dance groups for both genders ($P > 0.05$).

This significant advantage in external rotation relative strength is closely related to the characteristics of specialized training and physiological parameters. Ballet students tend to have a lower average body weight compared to the general population (especially among females), which enhances their power output efficiency relative to body weight. The research results confirm the sensitivity of relative strength indicators in specialized assessments. Compared to absolute peak torque, the inter-group differences in external rotation relative torque are more pronounced, offering a more accurate reflection of the optimizing effect of ballet training on the strength-to-body weight ratio. This adaptive change is in sync with the selection criteria for ballet programs—during the selection process, schools often prioritize candidates with lower BMI compared to the general population, thus achieving enhanced movement efficiency through a low body weight-high strength physiological configuration.

5.2.3 Relative Work (TW/BW)

Table 9: Relative Work of Hip Joint Internal and External Rotation (Unit: J/Kg)

		Internal Rotation		External Rotation	
Angle Velocity (°/s)		60	180	60	180
Male	Ballet	0.39±0.13	0.34±0.11	0.6±0.14	0.59±0.07
	Non-dance	0.44±0.09	0.39±0.06	0.48±0.08*	0.43±0.06***
Female	Ballet	0.3±0.08	0.25±0.06	0.56±0.1	0.49±0.12
	Non-dance	0.38±0.07*	0.31±0.05*	0.42±0.07***	0.34±0.07***

Note: *Significant differences when comparing ballet students and non-dance students: *P < 0.05; **P < 0.01; ***P < 0.001.

The test data (Table 9) shows that ballet students perform significantly better in relative work for hip external rotation. In the male ballet group, the relative work at 180°/s external rotation reached 0.59±0.07 J/kg, which was 37.2% higher than the non-dance group ($P < 0.001$), and at 60°/s the increase was 25.0% ($P < 0.05$). In the female group, the relative work for external rotation at 60°/s and 180°/s increased by 33.3% ($P < 0.001$) and 44.1% ($P < 0.001$), respectively.

Regarding internal rotation, the male ballet group's work at 60°/s (0.39±0.13 J/kg) was 11.4% lower than the non-dance group, but this difference was not statistically significant ($P = 0.213$). In females, the relative work for internal rotation at 180°/s (0.25±0.06 J/kg) was 19.4% lower than the non-dance group ($P < 0.05$).

The advantage in external rotation work is directly related to the biomechanical characteristics of ballet-specific movements. In daily training, the external rotation muscles are required to maintain a 170-

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180° abduction angle with continuous contraction. The low efficiency of the internal rotation muscles highlights the one-sided nature of the training system. Ballet training lacks internal rotation movements, which results in lower work efficiency for the internal rotation muscles at 60°/s (male: 0.39 J/kg vs. 0.44 J/kg; female: 0.30 J/kg vs. 0.38 J/kg) compared to the non-dance group.

The research results confirm that ballet training improves external rotation work capacity across a range of velocities. In the 60-180°/s testing range, external rotation work increased steadily by 25-44%, while the internal rotation muscles showed further reduced efficiency at high contraction speeds. This adaptive characteristic is related to the recruitment pattern of motor units: external rotation muscles, due to long-term training, have developed muscle fiber advantages that allow them to maintain efficient energy metabolism during fast contractions. In contrast, internal rotation muscles struggle to meet the power demands required during high-speed tests.

5.2.4 Relative Peak Power (PP/BW)

Table 10: Relative Peak Power of Hip Joint Internal and External Rotation (Unit: W)

		Internal Rotation		External Rotation	
Angle Velocity (°/s)		60	180	60	180
Male	Ballet	18.7±4.28	37.58±7.77	24.08±4.63	48.68±11.51
	Non-dance	14.43±3.16	28.79±7.23	14.47±2.28***	27.91±4.72***
Female	Ballet	8.8±1.95	16.96±3.2	13.24±2.22	24.52±5.64
	Non-dance	9.22±1.56	18.45±4.64	9.78±1.96**	18.35±5.21*

Note: *Significant differences when comparing ballet students and non-dance students: *P < 0.05; **P < 0.01; ***P < 0.001.

The test data (Table 10) shows that ballet students have a significant advantage in relative peak power for hip external rotation. The male ballet group achieved 48.68±11.51 W at 180°/s for external rotation, which was 74.4% higher than the non-dance group (P < 0.001), and at 60°/s, the increase was 66.4% (P < 0.001). In the female group, external rotation power increased by 35.4% (P < 0.01) at 60°/s and 33.6% (P < 0.001) at 180°/s.

Regarding internal rotation, the male ballet group showed an increase in internal rotation power of 29.7%-30.5% compared to the non-dance group (P > 0.05), while in the female ballet group, power at 180°/s (16.96 W) was 8.1% lower than the non-dance group (P = 0.187).

This advantage in external rotation power is attributed to the neuromuscular adaptations formed through specialized training. The ballet technical system emphasizes the rapid release of power during external rotation movements, such as in the Entrechat quatre (a type of jump where the legs are crossed in mid-air), where the external rotation muscles need to contract explosively in a very short amount of time. Weight management further enhances the relative power advantage. Ballet students generally have a lower average body weight compared to non-dance students, amplifying the power output per unit of body weight. This low weight-high power physiological adaptation aligns with the selection criteria for ballet students, who typically have a significantly lower BMI than non-dance individuals.

The delayed power development in internal rotation reflects the specificity of the training system. In ballet, the range of motion for internal rotation is often limited to 0-10°, such as during the initiation phase of a Pirouette (a type of spin), which explains the lower internal rotation power in ballet students.

5.2.5 Peak Torque Ratio (H/Q)

Table 11: Peak Torque Ratios of Hip Joint Internal and External Rotation

		Internal Rotation		External Rotation	
Angle Velocity (°/s)		60	180	60	180
Male	Ballet	0.73±0.15	0.73±0.17	1.42±0.28	1.43±0.33
	Non-dance	0.91±0.08**	0.91±0.15*	1.11±0.10**	1.12±0.18*
Female	Ballet	0.66±0.15	0.69±0.15	1.59±0.41	1.52±0.37
	Non-dance	0.94±0.16***	0.96±0.17***	1.1±0.2**	1.08±0.2**

Note: *Significant differences when comparing ballet students and non-dance students: *P < 0.05; **P < 0.01; ***P < 0.001.

The test data (Table 11) reveals that ballet students show a significant specialization in their hip internal and external rotation peak torque ratios. In the male ballet group, the internal rotation peak torque ratio at 60°/s (0.73±0.15) was 24.7% lower than that of the non-dance group (P < 0.01), and at 180°/s, it decreased by 19.8% (P < 0.05). The external rotation peak torque ratio, however, showed an increase—

male ballet students achieved 1.42±0.28 at 60°/s, which was 27.9% higher than the non-dance group ($P < 0.01$). In the female group, the differences were even more significant: the internal rotation ratio at 60°/s (0.66±0.15) was 29.8% lower than the non-dance group ($P < 0.01$), while the external rotation ratio at 180°/s (1.52±0.37) increased by 40.7% ($P < 0.001$).

These findings suggest that long-term ballet training significantly impacts the hip joint internal and external rotation peak torque ratios. Ballet students' internal rotation peak torque ratios are similar to or slightly lower than those of non-dance individuals, whereas their external rotation peak torque ratios are significantly higher. This is closely related to the specific external rotation training in ballet, where there is much more emphasis on strengthening the external rotation muscles of the hip joint, with little to no focus on internal rotation training. As a result, ballet students develop significantly stronger external rotation muscles compared to internal rotation muscles, whereas in non-dance individuals, the strength of the internal and external rotation muscles is generally similar. This leads to a pronounced difference in the hip joint internal and external rotation peak torque ratios in ballet students, which is a clear reflection of the specialized nature of their training.

6. Discussion

Based on the analysis and discussion of the five isokinetic strength test indicators for two types of hip joint movements (flexion-extension and internal-external rotation) in ballet majors and non-dance university students, as well as comparisons with athlete data, several conclusions can be drawn:

Firstly, ballet majors demonstrated higher values than non-dance students across all five indicators for hip flexion and extension strength—peak torque, relative peak torque, relative work, relative peak power, and peak torque ratio. This indicates that professional ballet training significantly enhances the maximal strength of the hip flexors and extensors, as well as their capacity for sustained force output and work performance. Notably, the maximal hip flexion-extension strength in male ballet students is comparable to that of fencing athletes.

Secondly, for hip internal rotation, ballet majors showed similar or even slightly lower values in all five indicators compared to non-dance students—peak torque, relative peak torque, relative work, relative peak power, and peak torque ratio. In contrast, ballet majors outperformed non-dance students across all five indicators for hip external rotation, with the peak torque ratio showing particularly strong specialization.

The significantly higher external rotation capability of the hip joint in ballet students is closely related to the demands of their specialized training and aligns well with theoretical expectations. Future studies should expand to other dance forms such as Chinese classical dance and modern dance. Comparative analysis across different dance styles will help deepen the understanding of strength characteristics in dance training.

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